AVAILABILITY ANALYSIS OF MSF DISTILLERS USING FAULT TREE LOGIC

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Contents

Summary

Availability analysis like fault tree logic is an efficient tool for the systematic investigation of complex processes. They can be employed for the quantification of operation disturbances and for comparison between different designs. Originally developed for safety analysis (hazards) in the chemical and nuclear industry these techniques are now often applied to analyse the availability of a process.

The principles of the deductive fault tree logic method are briefly discussed. With this method the failure of a system is defined and primary events causing this failure are systematically investigated.

Referring to the MSF process an overview on fault tree analyses published in the past is

presented and discussed. Failure rates and repair times for plant equipment of different process fields are summarised.

Based on long term operational data from 23 MSF distillers, fault trees for the three most important subsystems (brine heater, brine recirculation, blow down) are evaluated for the calculation of the individual availability and design aspects affecting availability. Special attention is drawn to the benefits of stand-by equipment, constant speed and variable speed pumps and further design aspects like once-through and brine recirculation mode.

The results clearly show that stand-by equipment should be eliminated in future MSF plants consisting of more than one unit as the extra investment costs exceed the benefits of the slightly higher availability. Furthermore, variable speed pumps without flow control valves are superior both in availability and operation costs (including investment). Further design aspects such simplified TBT control, brine heater protection against boiling and blow down flow control are systematically compared to present designs proving the advantages of simple but effective design with reduced equipment.

Considering future MSF plants, the central message of this work for improved design and operation is to simplify the design substantially. This shows a much higher potential than any sophisticated modelling control and simulation effort.

1. Introduction

MSF is a very stable and inherently safe process - there is no risk of:

- Process induced fire.
- Explosion by uncontrolled chemical reaction or accumulation of dusts.
- Sudden environmental pollution endangering the staff.
- Long term environmental pollution caused by hazardous plant failure.

Accordingly the analysis for the MSF process and the water supply system is related to:

1. Plant availability and possible damage to components (affecting specific water costs).
2. Comparison of different process alternatives with regard to reliability (e.g. pumps in once-through and brine re-circulation plants).
3. Investigation of water shortage scenarios caused by plant outages.

Point 3 is most important since security of water supply is essential for Abu Dhabi. A shortage scenario for a given system depends on availability of individual sub-systems. Water storage tanks and the town water supply grid are such sub-systems. The third sub-system are the distillers (point 1) which will be analysed in detail. Point 2 is important with regard to future process and equipment selection.

2. Theoretical Approach to Availability of Process and Plant Equipment

Publications on availability and safety analyses for MSF desalination plants are very rare for a variety of reasons:

1. MSF inherent safety risks are comparatively low.
2. Collection and evaluation of operational reports is very time consuming and often impossible because of insufficient documentation of an event.
3. Internal reports are usually not published.

Wangnick (1995) presented a log-sheet to be completed by the operation staff of the distillers in case of equipment failure and unplanned shutdown of the plant. Consequent and standardized logging and evaluation of events is mandatory for any availability analysis. In Taweelah A all alarms are logged by a process monitoring system. But information on plant outage or repair is not provided.

A theoretical approach for calculation of the availability of a water supply system with MSF desalination plants is presented in (Unione et al. 1980a and b). Another analysis is based on operation data (7 years) from the Jeddah 1 MSF distillers (Ibrahim et al. 1982a).

2.1. Availability of Single Components

Unione et al. (1980a) characterizes the transient of availability for a component by a first order Markov equation

$$\frac{dp(t)}{dt} = -f*(p(t)) + f*(p(t-T))$$

with the initial conditions $p(0) = 1$ and $p(t<0)=0$ and

$p(t)$ = availability (-)
f = failure frequency (1 per year)
T = repair time (year)

The model assumes a linear decay for the transient of availability which is expressed by the term $-f*[p(t)]$. The rate of growth into the operating state after a repair is $f*(p(t-T))$. Mathematical solutions for the availability as a function of time in case of constant repair times and failure frequencies are

$P(t) = e^{-ft}$ for $t<T$

With $U(x<0) = 0$ and $U(x>0) = 1$ as heavyside unit step function. For $t \rightarrow \infty$ the

$$p(t) = \sum_{n=0}^{\infty} \frac{[\lambda(t-nT)]^n e^{-\lambda(t-nT)}}{n!} U(t-nT) \; for \; t > T$$

availability approaches a constant value

$$\lim_{t\to\infty} p(t) = \frac{1}{1+fT}$$

and the corresponding unavailability

$$\lim_{t\to\infty} q(t) = 1 - p(t) = \frac{fT}{1+fT} \approx fT \text{ for } fT << 1$$

The latter result is evident as it is the ratio of the unavailable time $f*T$ and 100 per cent availability ($1+f*T$).

Possible modifications of the solutions are

1. Considering the age of the component or the sub-system since an increase of failure frequency can be expected with increasing lifetime of the equipment [i.e. $f(t+\Delta t) \geq f(t)$].
2. Repair time and failure frequency may be described by a probability distribution function instead of a fixed value.

However, data and figures about failure frequencies and repair time are usually too sparse to account for these two effects. There are two possibilities to obtain fixed repair times and failure rates for calculation

Consequent and detailed logging and evaluation of operation, shut-down and maintenance of the MSF process [as proposed by Babcock (1995)].

Using data bases [e.g. Gesellschaft fur Reaktorsicherheit (1998)].

The problem of the latter option is that the reported data may refer to equal components but different boundary conditions such as size, media, temperature, pressure or material. These parameters can strongly influence the outage rate and repair time. Possibility 1 has been applied by Ibrahim et al. (1982a) for Jeddah 1 (1972-1980) distillers and is presented below.

2.2. Availability of Components with Redundant Stand by Equipment

Essential process components are often provided with stand-by equipment. The failure probability of both components simultaneously is

$q_{\text{redundant}} = q^n_{\text{single}}$
n = number of parallel components
q_{single} = non-availability of single component

To profit from the reduction of failure rate by stand-by equipment, proper maintenance of the stand-by component is mandatory because immediate and successful switch from stand-by to operation mode must be guaranteed. For the Abu Dhabi distillers (Babcock 1995) no information is available for addressing the question whether a forced switch from stand-by to operation mode of e.g. a major pump prevented a plant shut down. This is the second important topic which could be investigated by consequent use of a log sheet as presented in Babcock (1995).

2.3. Systems or Subsystems of Single Components

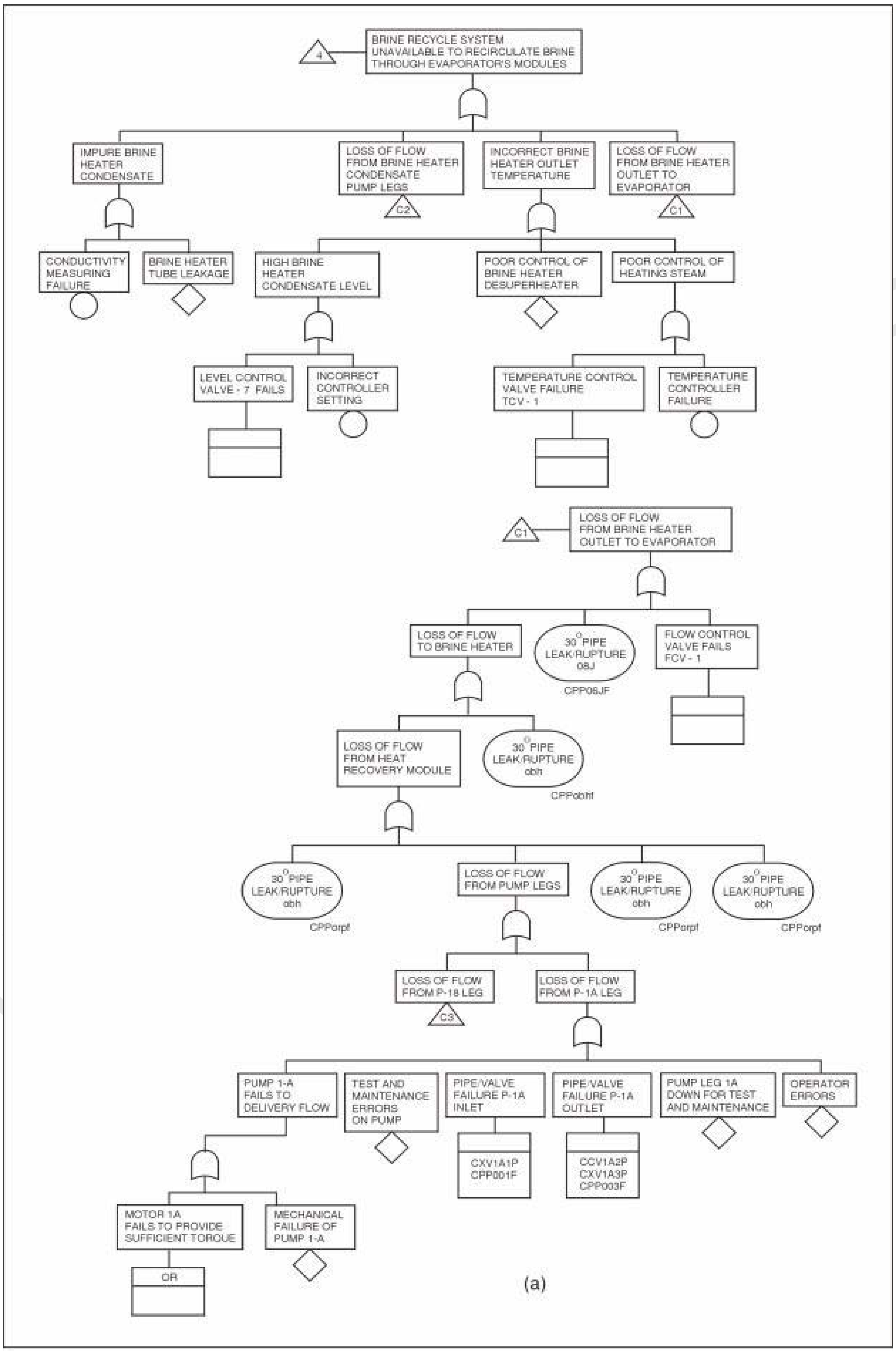
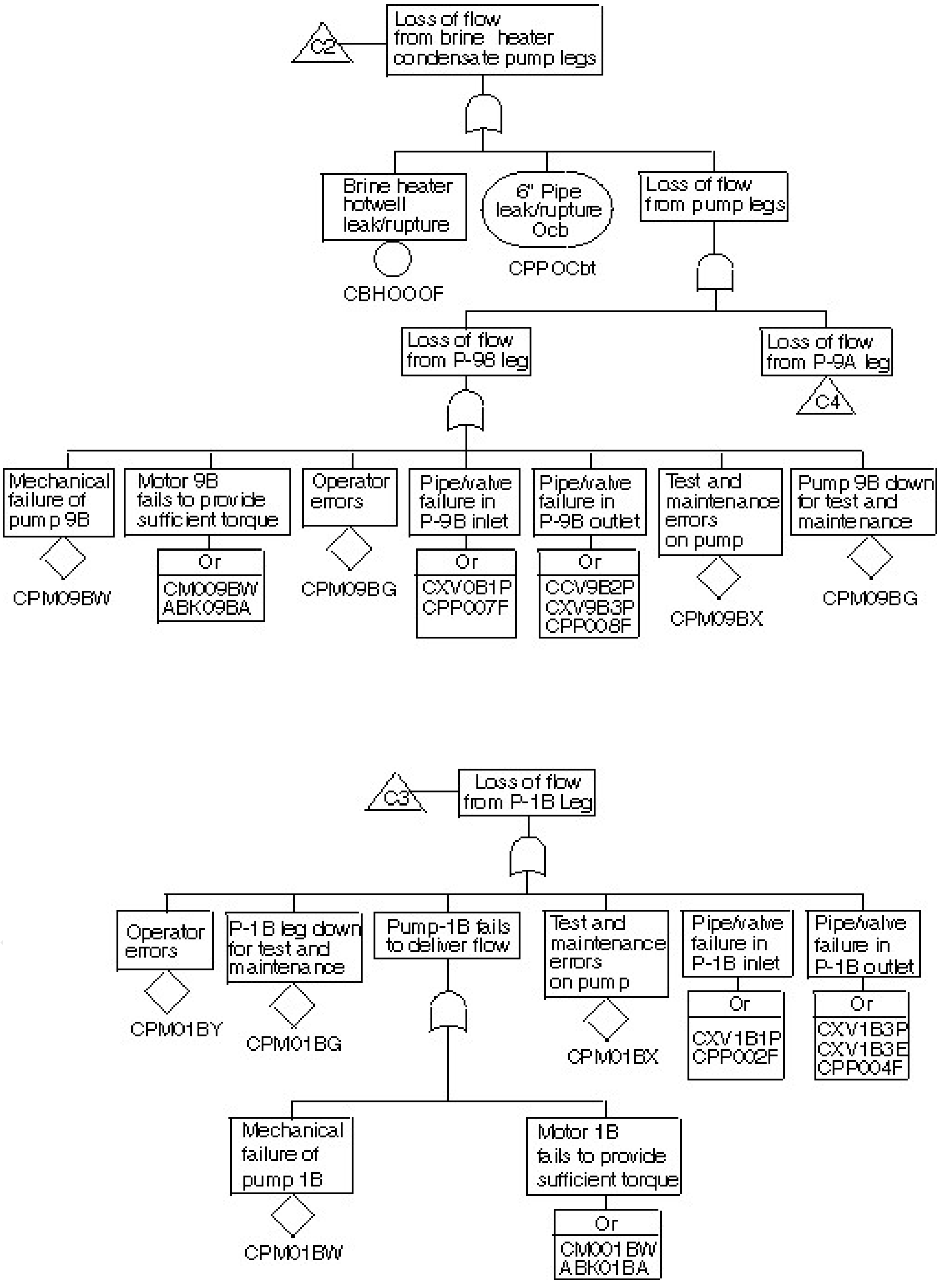


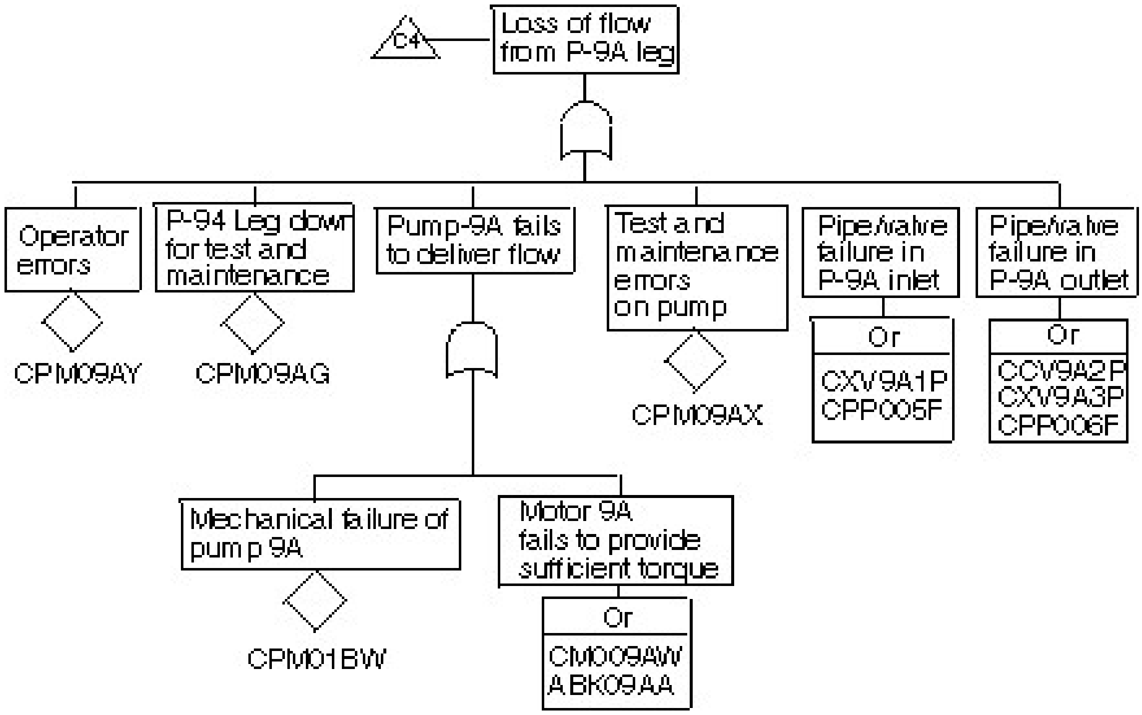
Figure 1(a). Fault tree logic of brine recirculation line (Ibrahim et al. 1982a)

A sub-system like e.g. the brine re-circulation line of a MSF plant or any other complex system usually consists of a number of components such as pumps, valves, pipes, instrumentation. The function of the system "brine re-circulation line" for example depends on the availability of all components involved. Figure 1 shows the fault tree logic for such a system.



(b)

Figure 1(b). Fault tree logic of brine recirculation line (Ibrahim et al. 1982a)



(c)

Figure 1(c). Fault tree logic of brine recirculation line (Ibrahim et al. 1982a)

It is obvious that the probability of a subsystem failure increases with increasing numbers of essential components involved and their individual availabilities. The total availability of such a sub-system is the product of all single availabilities (for low failure rates)

$$P_{subsystem} = \pi_{i=1}^{n} P_{single}$$

2.4. Redundant Systems and Subsystems with Planned and Unplanned Outages

Redundant systems have identical functions for the process investigated but may differ in structure. For example heating steam for the brine heater is provided either by power plant or auxiliary boilers or both. Both supply systems (power plant and auxiliary boiler) have different availabilities or outage rates. Planned outages for redundant systems are assumed not to be scheduled simultaneously. Therefore only the maximum planned outage rate of all main systems (see Figure 2, power plant) is used with all unplanned outages to calculate the overall availability of the system for steam supply.

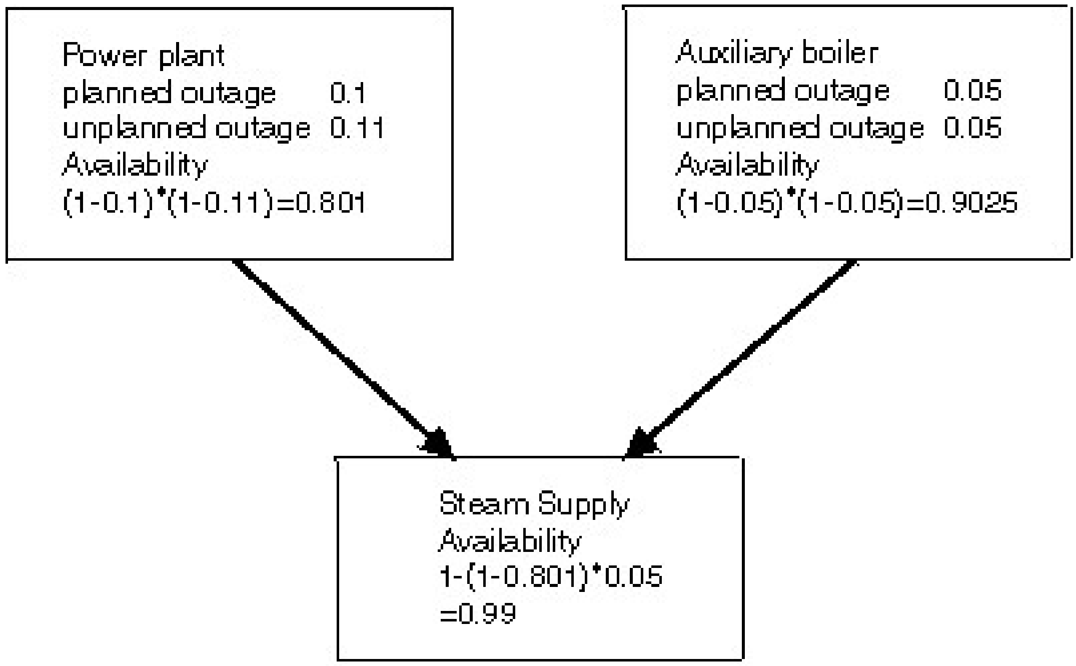


Figure 2. Availability of steam supply for desalination.

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